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METHOD FOR USING A NON-ORTHOGONAL PILOT SIGNAL
WITH DATA CHANNEL INTERFERENCE CANCELLATION

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CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Application Serial No.
60/184,365, filed February 23, 2000, and entitled "METHOD FOR USING A NON-ORTHOGONAL
PILOT SIGNAL WITH DATA CHANNEL INTERFERENCE CANCELLATION".

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to the field of data communications and
processing and, more particularly, to a method for encoding/decoding data channels in a
25 CDMA system having data channel interference cancellation.

2. Description of the Related Art

Code Division Multiple Access (CDMA) modulation is a multi-user access transmission scheme in which different users of the same transmission medium overlap both in frequency and in time. This is in contrast to Frequency Division Multiple Access (FDMA)

5 in which users overlap in time, but are assigned unique frequencies, and Time Division Multiple Access (TDMA) in which users overlap in frequency, but are assigned unique timeslots. According to CDMA, each user is assigned a unique code sequence that allows the user to spread its information over the entire channel bandwidth, as opposed to particular sub-channel(s) in FDMA. Thus, signals from all users are transmitted over the entire channel.

10 To separate out the signals for a particular user at a receiver, cross correlation is performed on the received signal using the same unique user code sequence.

CDMA transmission is well known to those of skill in the art. A comparison between CDMA and FDMA/TDMA may be found in Proakis, "Digital Communications", Chapter 15, which is incorporated herein by reference. Also, an example of a combined

15 approach for minimizing inter-user interference (i.e., combining a Walsh basis within a group and a spreading sequence across groups) is the IS-95 system described in TIA/EIA/IS-95 "Mobile Station Compatibility Standard for Dual Mode Wideband Spread Spectrum Cellular System", which is incorporated herein by reference.

An IS-95 CDMA system is unique in that its forward and reverse links (i.e., the

20 base station to mobile station and mobile station to base station) have different link structures. This is necessary to accommodate the requirements of a land-mobile communication system. The forward link consists of four types of logical channels, i.e., pilot, sync, paging, and traffic channels, with one pilot channel, one sync channel, up to seven paging channels, and several traffic channels. Each of these forward-linked channels is first spread orthogonally by its

25 Walsh function, and then spread by a pair of short PN sequences (so-called pseudonoise) each of which is a sequence of high data rate bits ("Chips") ranging from -1 to +1 (polar) or 0 to

1 (non-polar). Subsequently, all channels in the system are added together to form the composite spread spectrum signal which is transmitted on the forward link.

The reverse link in the IS-95 CDMA system consists of two types of logical channels, i.e., access and traffic channels. Each of these reverse-link channels is spread orthogonally by a unique long PN sequence; hence each channel is recovered or decoded using the distinct long PN code. In some instances, a pilot channel is not used on the reverse link based on the impracticality of each mobile station broadcasting its own pilot sequence. Additionally, the IS-95 CDMA system uses 64 Walsh functions which are orthogonal to each other (i.e., their cross-product is equal to zero), and each of the logic channels on the forward link is identified by its assigned Walsh function. The Walsh function is used to generate a code which is used to separate individual users occupying the same RF band to avoid mutual interference on the forward link. The access channel is used by the mobile station to communicate with the base station when a traffic channel is not assigned to the mobile station. The mobile station uses the access channel to generate call originations and respond to pages and orders. The baseband data rate of the access channel is fixed at 4.8 kilobits per second (Kbps).

The pilot channel is identified by the Walsh function 0 (ω_0). This channel contains no baseband sequence information. The baseband sequence is a stream of 0s which are spread by Walsh function 0, which is also a sequence of all zeros. The resulting sequence (still all 0s) is then spread or multiplied by a pair of quadrature PN sequences. Therefore, the pilot channel is effectively the PN sequence itself. The PN sequence with a specified offset uniquely identifies the particular geographical area or sector from which the user is transmitting the pilot signal. In an IS-95 CDMA system, both Walsh function 0 and the PN sequence operate at a rate of 1.2288 mega chips per second (Mcps). After PN spreading, baseband filters are used to shape the resultant digital pulses. These filters effectively lowpass filter the digital pulse stream and control the baseband spectrum of the signal. As a result, the signal band possesses a sharper roll-off near the band edge. The pilot channel is transmitted

continuously by the base station sector. The pilot channel provides the mobile station with timing and phase reference. The measurement of the signal-to-noise ratio of the pilot channel by the mobile station also provides an indication of the strongest serving sector of that mobile. Here, the signal-to noise is the energy per chip per interference density, or E_c/I_0, where E_c is

5   the energy per chip and I_0 is the interference density.

Unlike the pilot channel, the sync channel carries baseband information. The baseband information is contained in the *sync channel message* which notifies the mobile of information concerning system synchronization and parameters. Similar to the sync channel, the paging channel also carries baseband information. However, unlike the sync channel, the

10   paging channel transmits at a higher rate, i.e., at either 4.8 or 9.6 Kbps.

The forward and reverse traffic channels are used to transmit user data and voice; signaling messages are also sent over the traffic channel. The structure of the forward traffic channel is similar to that of the paging channel, while the structure of the reverse traffic channel is similar to that of the access channel. The only difference is that the forward traffic

15   channel contains multiplexed power control bits (PCBs) and the reverse traffic channel contains a data burst randomizer which is used to generate a masking pattern of 0s and 1s to randomly mask redundant data.

The techniques for separating signals in time (i.e., TDMA), or in frequency (i.e., FDMA) are relatively simple ways of ensuring that the signals are orthogonal and

20   noninterfereing. However, in CDMA, different users occupy the same bandwidth at the same, but are separated from each other via the use of a set of orthogonal waveforms, sequences, or codes. Two real-valued waveforms x and y are said to be orthogonal if their cross correlation R_{xy}

over time period T is zero, where

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$$R_{xy}(0) = \int_0^T x(t)y(t)dt \qquad \text{(Eq. 1)}$$

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In discrete time, the two sequences x and y are orthogonal if their cross-product $R_{xy}(0)$ is zero. The cross product is defined as

$$R_{xy}(0) = x^T y = \sum_{i=1}^{I} x_1 y_i \qquad \text{(Eq. 2)}$$

5

where

$$x^T = \begin{bmatrix} x_1 & x_2 \cdots x_I \end{bmatrix}$$

$$y^T = \begin{bmatrix} y_1 & y_2 \cdots y_I \end{bmatrix}$$

In this case, T denotes the vector transpose, i.e., a column represented as a row or vice versa.

10 For example, the following two sequences or codes, x and y are orthogonal:

$$x^T = \begin{bmatrix} -1 & -1 & 1 & 1 \end{bmatrix}$$

$$y^T = \begin{bmatrix} -1 & 1 & 1 & -1 \end{bmatrix}$$

because their cross-correlation is zero; that is

15 $$R_{xy}(0) = x^T y = (-1)(-1) + (-1)(1) + (1)(1) + (1)(-1) = 0 \qquad \text{(Eq. 3)}$$

In order for the set of codes to be used in a multiple access scheme, additional properties are required. That is, in addition to the zero cross-correlation property, each code in the set of orthogonal codes must have an equal number of 1s and -1s. This property provides each particular code with the required pseudorandom characteristic. An additional property is that

20 the dot product of each code scaled by the order of the code must equal to 1. The order of the code is effectively the length of the code, and the dot product is defined as a scalar obtained by multiplying the sequence by itself and summing the individual terms. This is given by the following relationship:

$$R_{xx}(0) = x^T x = \sum_{i=1}^{I} x_i x_i \qquad \text{(Eq. 4)}$$

The increasing use of wireless telephones and personal computers has led to a corresponding demand for such advanced telecommunications techniques as CDMA, FDMA and TDMA, which were once thought to be only meant for use in specialized applications. In

5   the 1980's wireless voice communication became widely available through the cellular telephone network. Such services were at first typically considered to be the exclusive province of the businessman because of high subscriber costs. The same was also true for access to remotely distributed computer networks, whereby until very recently, only business people and large institutions could afford the necessary computers and wireline access

10   equipment. As a result of the widespread availability of both technologies, the general population now increasingly wishes to not only have access to networks such as the Internet and private intranets, but also to access such networks in a wireless manner as well. This is of particular concern to the users of portable computers, laptop computers, hand-held personal digital assistants and the like who prefer to access such networks without being tethered to a

15   telephone line.

However, there is still no widely available satisfactory solution for providing low cost, broad geographical coverage, high speed access to the Internet, private intranets, and other networks using the existing wireless infrastructure. This situation is a result of several factors. For one, the typical manner of providing high speed data service in the business

20   environment over the wireline network is not readily adaptable to the voice grade service which is available in most homes or offices. Additionally, such standard high speed data services do not lend themselves well to efficient transmission over standard cellular wireless handsets. Furthermore, the existing cellular network was originally designed only to deliver voice services. As a result, the emphasis in present day digital wireless communication schemes lies

25   with voice, although certain schemes such as CDMA do provide some measure of asymmetrical

behavior for the accommodation of data transmission. For example, the data rate on an IS-95 forward traffic channel can be adjusted in increments from 1.2 Kbps to up to 9.6 Kbps for so-called Rate Set 1, and for increments from 1.8 Kbps up to 14.4 Kbps for Rate Set 2.

Existing systems therefore typically provide a radio channel which can accommodate maximum data rates only in the range of 14.4 Kbps at best in the forward direction. Such a low rate data channel does not directly lend itself to transmitting data at rates of 28.8 or even 56.6 Kbps which are now commonly available with conventional modem type equipment. Data rates at these levels are rapidly becoming the minimum acceptable rates for activities such as Internet access. Other types of data networks using higher speed building blocks such as Digital Subscriber Line (xDSL) service are just now coming into use. However, the cost of xDSL service has only recently been reduced to the point where it is attractive to the residential customer.

Although xDSL and Integrate Services Digital Network (ISDN) networks were known at the time that cellular systems were originally deployed, for the most part, there is no provision for providing higher speed ISDN or xDSL grade data services over cellular networks. Unfortunately, in wireless environments, access to channels by multiple subscribers is expensive and there is competition for them. Whether the multiple access is provided by the traditional FDMA using analog modulation on a group of radio carriers, or by the newer digital modulation schemes which permit sharing of a radio carrier using TDMA or CDMA, the nature of the radio spectrum is that it is a medium which is expected to be shared. This is quite different from the traditional environment for data transmission, in which the wireline medium is relatively inexpensive to obtain, and is therefore not typically intended to be shared. Accordingly, it is apparent that there is a need to provide a system which supports higher speed ISDN or xDSL grade data services over cellular network topologies. In particular, what is needed is an efficient scheme for supporting wireless data communication such as from portable computers to computer networks such as the Internet and private intranets using widely available infrastructure.

Most modern wireless standards in widespread use such as CDMA do not provide an adequate structure with which to support the most common activities, such as web page browsing. In the forward and reverse link direction, the maximum available channel bandwidth in an IS-95 type CDMA system is only 14.4 Kbps. Due to IS-95 being circuit-switched, there are only a maximum of 64 circuit-switched users that can be active at one time. In practicality, this limit is difficult to attain, and 20 or 30 simultaneous users are typically active at one time. Furthermore, existing CDMA systems require certain operations before a channel can be used. For example, both access and traffic channels are modulated by so-called long code pseudonoise (PN) sequences. In addition, in order for the receiver to work properly it must first be synchronized with the transmitter. The setting up and tearing down of user channels therefore requires overhead to perform such synchronization. This overhead results in a reduction of the system data rate which produces a noticeable delay to a user of a subscriber unit. Moreover, in the presence of benign cell conditions, the data rate of a conventional CDMA system may become limited by the number of available orthogonal code channels.

SUMMARY OF THE INVENTION

The present invention is directed to a method for encoding/decoding data channels in a system having data channel interference cancellation. In accordance with the invention, the data rate of a system for a given user is increased by using a non-orthogonal pilot signal for channelization. As a result, one or more orthogonal channels become available for user traffic, rather than for use by the pilot channel. This leads to a reduction in the number of occupied orthogonal channels and an increase in system capacity available for each user due to the attainment of higher data rates which permit faster data delivery to system subscribers.

The use of a non-orthogonal pilot signal requires interference cancellation to remove the modulation effects of the pilot signal upon the data signal. This is accomplished

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by regenerating interference terms with respect to the non-orthogonal pilot signal and subtracting them from the demodulated data signal.

BRIEF DESCRIPTION OF THE DRAWINGS

5   The present invention may be more readily understood by one skilled in the art with reference being had to the following detailed description of the preferred embodiments thereof, taken in conjunction with the accompanying drawings wherein like elements are designated by identical reference numerals throughout the several views, and in which:

Figure 1 is a block diagram of a wireless communication system which uses

10   interference cancellation on the pilot channel in accordance with the invention;

Figure 2 is a schematic block diagram of a CDMA transceiver for implementing the method in accordance with the present invention;

Figure 3 is an illustration of a pilot/data spreader of Fig. 2;

Figure 4 is an illustration of a data despreader of Fig. 2;

15   Figure 5 is an illustration of a pilot despreader of Fig. 2;

Figure 6 is an illustration of an interference cancellor of Fig. 2;

Figure 7 is an illustration of a dot product calculator of Fig. 2; and

Figures 8(a) and 8(b) are flow charts illustrating the steps of the method according to the invention.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a block diagram of a wireless communication system **100** which uses data channel interference cancellation to remove unwanted non-orthogonal pilot signal components present within the data signal. This results in a reduction in the number of

25   occupied orthogonal channels and an increase in system capacity. This yields an increase in the system data rate which results in a reduction of the delay experienced by the user of the

subscriber unit. As a result, high speed data and voice service over a wireless connection is achieved.

The system **100** includes two different types of components, such as subscriber units **101-1**, **101-2**,..., **101-u** (collectively, the subscriber unit **101**) and one or more base stations **170**. The subscriber units **101** and base stations **170** cooperate to provide the functions necessary to provide wireless data services to a portable computing device **110** such as a laptop computer, portable computer, personal digital assistance (PDA) or the like associated with a subscriber unit **101**. The base station **170** also cooperates with the subscriber units **101** to permit the ultimate transmission of data to and from the subscriber unit **101** and the public switch telephone network (PSTN) **180.** More particularly, data and/or voice services are also provided by the subscriber unit **101** to the portable computer **110** as well as one or more devices such as telephones. The telephones themselves may in turn be connected to other modems and computers which are not shown in Fig. 1.

The subscriber unit **101** itself may include a modem, such as an ISDN modem **120**, a device referred to herein as a protocol converter **130** which performs various functions including spooling **132** and bandwidth management **134**, CDMA transceiver **140**, and subscriber unit antenna **150**. The various components of the subscriber unit **101** may be realized in discrete devices or as an integrated unit. For example, an existing conventional ISDN modem **120** such as is readily available from any number of manufacturers may be used together with existing CDMA transceivers **140**. In this case, the necessary additional functions may be provided entirely by the protocol converter **130** which may be sold as a separate device. Alternatively, the ISDN modem **120**, protocol converter **130** and CDMA transceiver **140** may be integrated as a complete unit and sold as a single subscriber unit device **101**. Other types of interface connections such as Ethernet or PCMCIA may be used to connect the computing device to the protocol converter **130**. The device may also interface to an Ethernet interface rather than an ISDN "U" interface.

The ISDN modem **120** converts data and voice signals between the format used by the terminal equipment **110** and the format required by the standard ISDN "U" interface. The U interface is a reference point in ISDN systems that designates a point of the connection between the network termination (NT) and the telephone company.

5   The protocol converter **130** performs spooling **132** and basic bandwidth management **134** functions. In general, spooling **132** consists of insuring that the subscriber unit **101** communicates with the terminal equipment **110** which is connected to the public switched telephone network **180** on the other side of the base station **170** at all times. The bandwidth management function **134** is responsible for allocating and deallocating CDMA

10 radio channels **160** as required. Bandwidth management **134** also includes the dynamic management of the bandwidth allocated to a given session by dynamically assigning sub-portions of the CDMA radio channels **160**. The CDMA transceiver **140** accepts the data from the protocol converter **130** and reformats the data into the appropriate form for transmission through the subscriber unit antenna **150** over CDMA radio link **160-1**. The

15 CDMA transceiver **140** may operate over only a single 1.25 MHz radio frequency channel, or may be tunable over multiple allocatable radio frequency channels.

        CDMA signal transmissions from the subscriber units **101** are received and processed by the base station equipment **170**. The base station equipment **170** typically includes multichannel antennas **171**, multiple CDMA transceivers **172** and a bandwidth

20 management function **174**. Bandwidth management **174** controls the allocation of CDMA radio channels **160** and subchannels, in a manner analogous to the subscriber unit **101**. Transceiver **172** demodulates the received CDMA signals, and the base station **170** couples the demodulated radio signals to the PSTN **180** in a manner which is well known in the art. For example, the base station **170** may communicate with the PSTN **180** over any number of different efficient

25 communication protocols such as primary rate ISDN, or other LAPD based protocol such as IS-634 or V5.2.

It should also be understood that data signals travel bidirectionally across the CDMA radio channels **160**. In other words, data signals received from the PSTN **180** are coupled to the portable computer **110** in a forward link direction, and data signals originating at the portable computer **110** are coupled to the PSTN **180** in a reverse link direction.

5 　　　　　　Each of the CDMA transceivers such as transceiver **140** in the subscriber unit **101**, and transceivers **172** in the base station **170**, are capable of being tuned at any given point in time to a given 1.25 Megahertz radio frequency channel. It is generally understood that such 1.25 MHz radio frequency carrier provides, at best, a total equivalent of about 500, 600 kbps maximum data rate transmission within acceptable bit error rate limitations.

10 　　　　　　Figure 2 is a schematic block diagram of CDMA transceivers **140**, **172** of the wireless communication system **100** for implementing the method according to the present invention. Specifically, Fig. 2 is a block diagram of a transmitter portion of a transceiver **140** and a receiver portion of transceiver **172**. Initially, pilot spreader **201** is used to modulate a non-orthogonal pilot signal such that the pilot signal is spread over an entire channel

15 bandwidth. Concurrently, data spreader **204** is used to spread data over the same channel bandwidth. The spread pilot and data signals are then combined to form a composite signal *S(t)* which is transmitted to base station **170** for despreading by pilot despreader **202** and data despreader **205**, respectively. The despreaders **202**, **205** are used to recover the non-orthogonal pilot signal and the data signal, respectively, from the transmitted composite

20 signal *S(t)*. The outputs of the pilot despreader **202** and data despreader **205** are fed to an interference canceller **203** which is used to remove interference introduced into the data signal by the non-orthogonal pilot signal. Once the interference from the non-orthogonal pilot signal is removed by the interference canceller **203**, the original data is recovered via dot product calculator **206** and output for later processing by a communications system (not shown).

25 　　　　　　Figure 3 is a block diagram of a pilot/data spreader **201** and **204** of Fig. 2 which are used to modulate the non-orthogonal pilot and data signals such that they are spread over an entire channel bandwidth. At nodes **201a** and **201b** of the pilot spreader **201**, a

non-orthogonal pilot signal P is modulated by a channel code p_c which is used to uniquely identify the transmitted pilot signal P. At nodes **204a** and **204b** of the data spreader **204**, a data signal which is split into sub-band data I and Q is mixed with a signal g_i which represents a specific channel code of a user (I and Q represent the in-phase and quadrature portions of the data signal, respectively). At node **201c/204c**, the output signal from node **201a** is summed with the output signal from node **204a** to produce a resultant signal. Simultaneously, at node **201d/204d**, the output signal from node **204b** is summed with the output signal from node **201b** to produce a resultant signal.

At nodes **201e/204e** and **201f/204f**, the resultant signals are each modulated by a PN code a. Next, in order to provide baseband or phase discrimination between the I and Q sub-band portions of the data signal, the output signals of nodes **201e/204e** and **201f/204f** are modulated (i.e., spread) by channel separation signals w_I and w_Q, respectively, at nodes **201g/204g** and **201h/204h**, respectively. In this case, the channel separation signals w_I and w_Q belong to a family of orthogonal functions such as those disclosed in U.S. Patent No. 4,460,992 to *Gutleber*, which is incorporated herein by reference as if set forth expressly. Each respective channel separation signal spreads the in-phase portion and quadrature portion of the data signal to produce composite signals. At the nodes **201i/204i** and **201j/204j**, the respective composite output signals from nodes **201g/204g** and **201h/204h** are subsequently modulated by respective cosine and sine functions (i.e., $\cos(wt+\theta)$ and $\sin(wt+\theta)$). The output signals from nodes **201i/204i** and **204j/201j** are then summed to form a composite signal $S(t)$ given by the following relationship:

$$S(t) = Pap_c w_I \cos(wt + \theta) + Pap_c w_Q \sin(wt + \theta) + I_n aw_I g_i \cos(\omega t + \theta)$$
$$+ Q_n aw_Q g_i \sin(\omega t + \theta) \qquad \text{(Eq. 5)}$$

The signal given by the relationship in equation 5 is transmitted to base station **170** which contains a data despreader **205** (see Fig. 6) for use in the demodulation of the transmitted composite signal $S(t)$ to recover the original data signal.

Figure 4 is a schematic block diagram of a data despreader **205** which is used in the recovery of the originally transmitted data signal. In the data despreader **205** shown in Fig. 4, the signal $S(t)$ given in equation 5 is initially decoded by demodulating $S(t)$ by $\cos(wt)$ and $\sin(wt)$ at nodes **205a** and **205b**, respectively to produce resultant output signals. Next, at nodes **205c** and **205d**, the resultant output signals from nodes **205a** and **205b** are demodulated by the PN code a. The output signals of nodes **205c** and **205d** are each demodulated by the channel separation function w_Q at nodes **205f** and **205g**, respectively. Concurrently, the output signal of node **205c** is demodulated by the channel separation function w_I at node **205e**, while at node **205h** the output signal of node **205d** is demodulated by a channel separation function $-w_I$ which is a complex conjugate of the channel separation function w_I. The output signals of nodes **205e**, **205f**, **205g** and **205h** are respectively demodulated at nodes **205i**, **205j**, **205k** and **205l** by the channel code of a user g_i.

Given two codes A and B of length n, an integration and dump function occurs when the lengths of the codes are matched, multiplied together, integrated and the result output for further processing. In this manner, an integration and dump function is then performed at nodes **205m-205p**, respectively, upon the output signals of nodes **205i-205l** to obtain the following relationships:

$$\sum_N (P_I(t) + S_I(t)) a w_Q g_i = \frac{N}{2} Q_n \sin(\theta) + \frac{1}{2} \sum_N Pg_i p_c \sin(\theta) + \frac{1}{2} \sum_N Pg_i p_c w_I w_Q \cos(\theta)$$

(Eq. 6)

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$$\sum_N (P_I(t) + S_I(t))aw_I g_i = \frac{N}{2} I_n \cos(\theta) + \frac{1}{2}\sum_N Pg_i p_c \cos(\theta) + \frac{1}{2}\sum_N Pg_i p_c w_I w_Q \sin(\theta)$$

<div align="right">(Eq. 7)</div>

$$\sum_N (P_Q(t) + S_Q(t))a(-w_i)g_i = \frac{N}{2} I_n \sin(\theta) + \frac{1}{2}\sum_N Pg_i p_c \sin(\theta) - \frac{1}{2}\sum_N Pg_i p_c w_I w_Q \cos(\theta)$$

<div align="right">(Eq. 8)</div>

$$\sum_N (P_Q(t) + S_Q(t))aw_Q g_i = \frac{N}{2} Q_n \cos(\theta) + \frac{1}{2}\sum_N Pg_i p_c \cos(\theta) - \frac{1}{2}\sum_N Pg_i p_c w_I w_Q \sin(\theta)$$

<div align="right">(Eq. 9)</div>

where each summation term in equations 6-9 represents interference due to the pilot signal which must be removed to accurately reconstruct the originally transmitted data signal, and each N in the summation is the processing gain.

Figure 5 is an illustration of the pilot despreader **202** which is used to recover the originally transmitted pilot signal P. To accomplish this, the transmitted composite signal $S(t)$, given by the relationship in equation 14, is demodulated by cosine and sine functions (i.e., $\cos(\omega t)$ and $\sin(\omega t)$) at nodes **202a** and **202b**. Next, the output signals from nodes **202a** and **202b** are demodulated by the PN code a at nodes **202c** and **202d**, respectively. The output signals from nodes **202c** and **202d** are each demodulated by the channel separation function w_Q at nodes **202f** and **202g**, respectively. Concurrently, the output signal of node **205c** is demodulated by the channel separation function w_I at node **202e**, while at node **202h** the output signal of node **202d** is demodulated by the channel separation function $-w_I$. The output signals of nodes **202e**, **202f**, **202g** and **202h** are respectively demodulated at nodes **202i**, **202j**, **202k** and **202l** by the channel code p_c which is used to uniquely identify the transmitted pilot signal P. After demodulating the output signals of nodes **202i-202l**, the integration and dump

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function is performed to obtain the output signals given by the following relationships at nodes **205m**, **205n**, **205o** and **205p**, respectively:

$$\sum_N (P_I(t) + S_I(t)) a w_I p_c = \frac{N}{2} P \cos(\theta) + \frac{1}{2} \sum_N I_n g_i p_c \cos(\theta) + \frac{1}{2} \sum_N Q_n g_i p_c w_I w_Q \sin(\theta)$$

(Eq. 10)

$$\sum_N (P_I(t) + S_I(t)) a w_Q p_c = \frac{N}{2} P \sin(\theta) + \frac{1}{2} \sum_N Q_n g_i p_c \sin(\theta) + \frac{1}{2} \sum_N I_n g_i p_c w_I w_Q \cos(\theta)$$

(Eq. 11)

$$\sum_N (P_Q(t) + S_Q(t)) a(-w_i) p_c = \frac{N}{2} P \sin(\theta) + \frac{1}{2} \sum_N I_n g_i p_c \sin(\theta) - \frac{1}{2} \sum_N Q_n g_i p_c w_I w_Q \cos(\theta)$$

(Eq. 12)

$$\sum_N (P_Q(t) + S_Q(t)) a w_Q p_c = \frac{N}{2} P \cos(\theta) + \frac{1}{2} \sum_N Q_n g_i p_c \cos(\theta) - \frac{1}{2} \sum_N I_n g_i p_c w_I w_Q \sin(\theta)$$

(Eq. 13)

where N is the processing gain.

As shown in Figure 5, four output signals are generated which each contain interference as a result of the demodulation process. Equations 10-13 represent the output signal at nodes **202m**, **202n**, **202o** and **202p**, respectively. In this case, the eight summation terms in equations 10-13 represent the interference added to the pilot signal as a result of the demodulation process. At node **202q**, the output signals from nodes **202m** and **202o** are subsequently subjected to an additional integration and dump function, while the integration and dump function is performed on the output signals from nodes **202n** and **202p** at node **202r**. As a result, the signals are filtered such that the interference is removed and the originally transmitted pilot signal P is recovered.

Along with the output of the pilot despreader **202**, the output of the data despreader **205** is provided to an interference canceller **203** shown in Fig. 6. The output of the pilot despreader is fed to the input of the interference canceller **203**, and the output of the interference canceller **203** is subtracted from the output of the data despreader **205** in a manner

5   which is known to yield I and Q sub-band data signals which do not contain interference associated with the pilot signal P.

The interference canceller **203** shown in Fig. 6 is used to remove the interference associated with the pilot signal P which is introduced into the data signal during the demodulation process. The interference added to the data signal is represented by the

10   summation terms in the relationships given in equations 6-9. To remove the interference from the despread data signals, the $P\cos(\theta)$ and $P\sin(\theta)$ inputs of the interference canceller **203** are each modulated by the channel code p_c at nodes **203a** and **203b**, respectively. Next, the output signals of nodes **203a** and **203b** are each modulated by the group user channel code g_i. At this point, an integration of the output signals of nodes **203c** and **203d** is performed to yield

15   respective first and second interference terms given by the following relationships:

$$\frac{P\cos(\theta)}{2} \sum_N g_i p_c \qquad \text{(Eq. 14)}$$

and

$$\frac{P\sin(\theta)}{2} \sum_N g_i p_c \qquad \text{(Eq. 15)}$$

20   where N is the processing gain.

Next, the output signals from nodes **203c** and **203d** are modulated by the w_I channel separation function at nodes **203g** and **203h**, respectively. The output signals from nodes **203g** and **203h** are then modulated by the channel separation function w_Q at nodes **203i**

25   and **203j**, respectively. An integration of the output signals from nodes **203i** and **203j** is

performed at nodes **203k** and **203l** to yield respective third and forth interference terms given by the following relationships:

$$5 \qquad \frac{P\cos(\theta)}{2} \sum_{N} g_{i} p_{c} w_{I} w_{Q} \qquad \text{(Eq. 16)}$$

and

$$10 \qquad \frac{P\sin(\theta)}{2} \sum_{N} g_{i} p_{c} w_{I} w_{Q} \qquad \text{(Eq. 17)}$$

where N is the processing gain.

The relationships expressed in equations 14-17 are subtracted from the respective expressions found in equations 6-9 to remove the interference from the I and Q sub-band data signals. At this point, once the interference is removed from the data signal, complete recovery of the data signal is possible.

Figure 7 is an illustration of an exemplary dot product calculator **206** for performing a dot product calculation to recover the original data signal. After removal of the interference terms given in equations 14-17, each respective portion of the I_n and Q_n sub-band data signals is forwarded to the dot product calculator **206**. The respective cosine and sine portions of the pilot signal P which are output from the pilot despreader **202** are also forwarded to the dot product calculator **206**, as shown in Fig. 7. At nodes **206a** and **206b**, the cosine portion of the pilot signal P is modulated by the cosine portions of the I_n and Q_n sub-band data signals. Simultaneously, at nodes **206c** and **206d**, the sine portion of the pilot signal P is modulated by the sine portions of the I_n and Q_n sub-band data signals. At node **206e**, the output signal of nodes **206a** and **206c** are summed together to yield an output signal given by the following relationship:

$$PI_{n} \cos(\theta - \hat{\theta}) \approx PI_{n} \qquad \text{(Eq. 18)}$$

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At node **206f**, the output signals of nodes **206b** and **206d** are summed together to yield another output signal given by the following relationship:

$$PQ_n \cos(\theta - \hat{\theta}) \approx PQ_n \qquad \text{(Eq. 19)}$$

where the ^ term in equations 18 and 19 indicates a coarse estimate of the phase over one symbol (i.e., the number of chips per signal). At this point, one skilled in the art will readily appreciate that equations 18 and 19 represent the originally transmitted I and Q sub-band data signals, where each sub-band is multiplied by the pilot signal P.

Figures 8(a) and 8(b) are flow charts of the method for using a non-orthogonal pilot signal according to the invention. In step **10**, a non-orthogonal pilot signal P is modulated by a channel code p_c. Simultaneously, a data signal which is split into sub-band data I and Q is mixed with a specific channel code of a user g_i. In step **20**, the non-orthogonal pilot signal is then summed with the I and Q sub-band data signals to produce resultant signals.

In step **30**, the resultant signals are then modulated by a PN code a. In step **40**, to provide baseband or phase discrimination between the I and Q sub-band portions of the data signal, the resultant output signals are modulated (i.e., spread) by channel separation signals w_I and w_Q. In step **50**, the respective composite output signals are modulated by respective cosine and sine functions (i.e., $\cos(wt + \theta)$ and $\sin(wt + \theta)$). In step **60**, the cosine and sine output signals are then summed to form the composite signal $S(t)$ which is transmitted to the base station **170**.

In step **70**, the composite signal $S(t)$ is initially decoded by demodulating it with $\cos(wt)$ and $\sin(wt)$. Next in step **80**, the resultant output signal is demodulated by the PN code a. In step **90**, the resultant signal is demodulated by the channel separation function w_Q. Concurrently, the resultant signal with respect to $\cos(wt)$ is demodulated by the channel separation function w_I, while the resultant signal with respect to $\sin(wt)$ is demodulated by a channel separation function $-w_I$. In step **100**, the signals which were demodulated by the

channel separation function w_Q are then demodulated by the channel code of a user g_i and the channel code p_c.

In step **110**, an integration and dump function is performed upon the resultant output signal to obtain the demodulated data signal containing the interference. Concurrently, an integration and dump function is also performed to obtain the demodulated non-orthogonal pilot signal. In step **120**, the demodulated non-orthogonal pilot signal is subjected to an additional integration and dump function to remove interference from the originally transmitted non-orthogonal pilot signal P.

In step **130**, the demodulated non-orthogonal pilot signal is modulated by the channel code p_c. In step **140**, the modulated pilot signal is modulated by the group user channel code g_i. In step **150**, an integration of the signal is performed to yield first and second interference terms. In step **160**, the signal modulated by the user channel code g_i is additionally modulated by the w_I channel separation function. In step **170**, the resultant signal is then modulated by the channel separation function w_Q. In step **180**, an integration of the resultant signal is performed to yield third and forth interference terms. In step **190**, the interference terms are subtracted from the demodulated data signal to remove the interference from the I and Q sub-band data. Finally, in step **200**, a dot product calculation is performed to recover the originally transmitted I and Q sub-band data signals.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.